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THE AIMS AND METHOD OF GEOLOGICAL INQUIRY.

THE INAUGURAL LECTURE

*At the Opening of the Class of Geology and Mineralogy in the University
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BY

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INAUGURAL LECTURE.

I N entering upon the duties of this CHAIR I can hardly do better, perhaps, than try to set before you what are the primary aims and general bearings of that branch of Natural Science which we are about to study, and to indicate the nature of the problems with which it deals. In doing so I will endeavour at the same time to point out the method of research and the mode of reasoning which we must pursue if we are to be successful investigators. Geology (in which comprehensive term I include Mineralogy and Palæontology), is concerned in the first place with observations of minerals, rocks, and fossil organic remains, and in the second place with the inferences which may be drawn from those observations. Its object is thus not only to note the nature and position of the various materials which constitute the solid crust of our globe, but by processes of inductive and deductive reasoning to ascertain how minerals and rocks have been formed and caused to assume the different appearances which they now present. In few words, then, our science might be defined as an inquiry into the history or development of the earth's crust, and of the several floras and faunas which have clothed and peopled its surface. It thus treats of the genesis of oceanic and continental areas—of mutations of climate—of the appearance and disappearance of successive tribes of plants and animals. More than this, in revealing the past it throws strong light upon the

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present, and has, perhaps more than any of the cognate sciences, tended to revolutionise our conceptions of Nature, and to lead zoologists and botanists into fruitful fields of inquiry which their own proper studies, no matter how assiduously prosecuted, could never have enabled them to reach.

Dealing, as Geology does, with the operations of Nature in the past, it is obvious that before we proceed to interpret the record of the rocks we ought to have a clear knowledge of the mode in which Nature works at present. Without this preliminary knowledge, it is just as hopeless to attempt to decipher that record as it would be to endeavour to understand a page of Greek without having first mastered the grammar and rudiments of that language. We must turn our attention then, at the very outset, to a study of those great forces by the action of which the crust of our globe is being continually modified. It is essential that we learn to appreciate the work done by the atmosphere, by frost and snow and ice, by rain and underground water, by rivers and lakes, by the sea, by plants and animals, and by the subterranean forces, before we can hope to recognise the different parts which those various agents of change have performed in the past. All geologists are agreed upon this, and are ready to acknowledge it as the chief article of their faith. Nevertheless, this obligatory article has received different interpretations. Some, for example, have held that the present condition of things must be taken as the exact type of all the phases through which the earth's surface has passed, during the different stages of which we have any recognisable records preserved to us in the stratified rocks of the globe. They admit that countless modifications of land and sea have taken place—that the climate of particular areas has varied again and again—that the subterranean and volcanic forces have manifested themselves with varying intensity, now in one place, now in another—but they hold that all these changes have been

accomplished upon the same scale and at the same rate as at present, and that, as a consequence, the development of floras and faunas, so far as that is dependent upon physical conditions, has proceeded no more rapidly in former times than in our own day. They do not, indeed, deny that in the very earliest stages of the earth's history the agents of geological change must have acted with greater intensity than now, but of such a period, they tell us, we have no certain evidence treasured up in the sedimentary rocks, or at least such evidence, if it should exist, has not yet been detected. Only allow time, they say, and the constant drop will wear away the hardest stone. The gradual elevation of land, which is now going on in certain parts of the globe at so slow a rate that some have been inclined to doubt whether there is any movement at all, would nevertheless suffice in time to lift tracts now within tide-wash into stupendous table-lands and mountains. Nor is it necessary, we are assured, to suppose that the apparent evidence of convulsive rending and displacement of strata, which is often so conspicuous in the heart of great mountain-chains and ranges, is really any proof of paroxysmal action. All the rupturing and confusion which we may note among the Alps and not a few mountain-regions may quite well have been brought about, we are informed, in the most gentle and gradual manner.

Other theorists, again, are of opinion that, while the agents of change have necessarily been through all time the same in kind, they have yet varied again and again in degree, and that the present moderate condition of things cannot therefore be taken as an exact type and pattern of all preceding phases in the world's history. They cannot allow that the elevation of mountain-chains and the larger fractures and displacements of strata are the result of the repetition of such small movements of the crust as are taking place now. Admitting that considerable areas of the earth's surface are rising at the rate of a yard or more in a century, they yet

cannot agree that this is a criterion by which to estimate the time required for the elevation of all protuberant parts of the earth's crust. They remind us that in our own day we have had experience of paroxysmal changes of level, nor can they doubt that similar sudden catastrophies must have happened oftentimes in the lapse of ages. They point to the appearances of ruin and confusion which may be traced along a line of mountain-elevation, and maintain that the broken and shattered strata are proofs of a more or less sudden yielding to enormous strain or tension. They do not deny that upheaval may have been going on over a given area at an extremely slow rate during long periods of time, but they argue that a point would at last be reached when the tension to which the strata were subjected could no longer be resisted. A sudden fracturing would at last take place—the strata would be violently dislocated, thrust forward, crumpled, and heaped, as it were, in confused and steeply-inclined masses along the main line of dislocation. Again, it is objected to uniformitarian views that these do not explain and cannot account for certain remarkable mutations of climate which are known to have occurred. It is not denied that the earth has been receiving for untold ages the same annual amount of heat from the sun, but it is maintained that, owing to certain astronomical changes, and the modifications induced thereby, that heat must have been very differently distributed over the globe at various epochs in the past. It is held, in short, that the climate both of the Northern and the Southern Hemispheres has thus been frequently modified, and that in consequence of this the action of the geological agents has been influenced again and again—the decay and reconstruction of rocks—the oscillations of the land—and the development of flora~~s~~ and fauna~~s~~ having been alternately accelerated and retarded according as extreme or moderate conditions prevailed.

Thus each school has its own method of interpreting the

fundamental axiom of our science—that the Present is the key to the Past. And as the primary aim of Geology is to interpret the stony record with a view to the reconstruction of our earth's history, it is obviously important that we should be able to satisfy ourselves as to which of these rival conceptions is most consonant with truth. In other words, we must do our utmost to ascertain which gives the most reasonable interpretation of geological phenomena. Each view must in its turn be tested by an appeal to facts, and a rigorous application of logical analysis. Probably we shall find that while there is much to be said on both sides, we can agree entirely neither with the one school nor the other. Before we are in a position, however, to discuss such questions, we must first have ranged over a very wide field of inquiry, and obtained a thorough grasp of the principles of our science.

Meanwhile, our chief concern in beginning our studies must necessarily be to detect resemblances between the present and the past. For every observation we make we must endeavour to discover a correlative phenomenon in the present order of things. And so long as we confine our attention to the facts before our eyes and to the more obvious interpretations of these which are suggested by forces now in action, we shall not fail to be impressed with the uniformity of Nature.

We examine, let us suppose, a section of strata exposed upon the sea-shore or along the banks of a river. Our knowledge of the different kinds of sediment in course of transportation and accumulation at the present day enables us at once to recognise, in the conglomerate sandstone and shale of our section, simply the consolidated sediments of earlier times. The occurrence of fossils in the strata determines whether the deposits were formed in fresh water, brackish water, or the sea—whether near to a coast-land, or at a greater distance from the shore, and so forth. If some of the fossils be of terrestrial origin, while others are brackish-

*brackish
water*

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water and marine, we gain not only certain knowledge of the life of the period, but, if the evidence be full enough, we may even form more or less reliable conclusions as to the physical and climatic conditions which at one time existed in the locality under our examination. In short, there are many almost obvious conclusions, as we may term them, which the appearances presented by an individual exposure of rocks must suggest to any observer who has previously become familiar with the operation of the natural forces in the world around us. He simply compares the facts with what is now taking place, and is thus led to conclude that effects the same in kind have been produced in the same way.

Sometimes, however, the rocks present appearances which are harder to interpret in this obvious and ready manner. We encounter, for example, a rock-mass having none of the features presented by ordinary sedimentary strata. Instead of being made up, like conglomerate and sandstone, of rounded stones or grains, arranged in layers, it is entirely composed of larger and smaller crystalline particles, not lying in lines and layers, but scattered indiscriminately through the whole mass. It does not occur in beds like ordinary sedimentary strata, but on the contrary we see it cutting, as it were, across other rocks, and sending out veins which penetrate the latter in all directions. The observer immediately concludes that the crystalline rock is of younger age than the beds traversed by it; and not only so, but that the whole mass with all its veins was injected into its present position in a liquid, semi-liquid, or pasty, and probably heated condition. And in confirmation of this last conclusion he may perhaps note that the rocks immediately adjoining the dykes and veins betray the appearance of having been subjected to the action of heat. The grits, we shall suppose, are hardened and much cracked and shattered, and the shales baked and porcellanized; both rocks, when closely examined, showing traces of an incipient fusion along the line of con-

tact with the intrusive rock. They may even lose their original granular texture and assume a more or less crystalline aspect for some distance away from the dykes and veins that intersect them. All these features the observer may have seen exemplified in a modern volcanic district, and he may therefore feel justified in the opinion he has formed as to the formerly molten state and therefore igneous origin of our crystalline rock. His induction, however, is not complete. He compares his supposed igneous rock with the undoubted products of existing volcanoes, and although many of these last send out dykes and veins and have a crystalline texture, yet not a single one may have any further resemblance to the crystalline rock of his section. He cannot, therefore, be any longer certain that his dykes and veins have originated in the same way as those of Etna and Vesuvius. The origin of such a crystalline rock as I am speaking of (which we may suppose is granite), cannot be determined, like that of conglomerate or sandstone, by direct comparison with similar rocks in process of formation. Exhaustive examination of the granite itself, an intimate knowledge of its ingredients, and the conditions of formation which these imply, combined with careful observation of the mode in which this rock occurs wherever it is met with—these and other studies must be prosecuted before any assurance can be obtained as to the precise mode in which granitic dykes and veins have originated. The observer then learns that these are really of igneous origin, as he at first inferred, but his notion that they have been injected into strata at or near the surface like the dykes of modern volcanoes cannot, he finds, be maintained. All the evidence supplied by careful microscopical examination and physical considerations leads to the conclusion that granite has been formed and consolidated at considerable depths. Having satisfied himself upon this point, the observer will readily conclude that the dykes and veins that now appear at the surface were formerly

buried under great masses of rock which have since been removed. Of course there are many other facts connected with the history of granite which I do not touch upon at present. By and by we shall learn that all masses of granite are not intrusive, but that certain considerable areas of this rock, although agreeing in composition with the granite of dykes and veins, are nevertheless not irruptive.

The conclusion that granite is of deep-seated origin is not, you will observe, contrary to our canon that the past is to be interpreted by the present. Molten rock, as we know, is forced into fissures in the neighbourhood of active volcanoes, and there consolidated, and chemical analyses show that some volcanic rocks have the same ultimate composition as granite. Partly by observation and partly by experiment we detect in granite evidence to prove that it has consolidated under pressure, and that, had the original molten mass cooled more rapidly and under moderate pressure, the resulting rock would have presented a very different appearance. Had injection taken place at or near the surface, or had the melted matter flowed out of a volcanic orifice, it might well have resembled some of the products of modern volcanoes.

Let us now take another sample of the mode of interpreting geological phenomena. We shall go back to our section of conglomerate, sandstone, and shale—and these deposits we shall suppose belong to a comparatively recent date—to the Tertiary Period, let us say. Suppose, moreover, that the fossils are numerous, and so well preserved that we are enabled to compare them with living forms. A few, we find, belong to existing species, others are closely related to these, while yet others, although without doubt extinct, can nevertheless be referred with confidence to living genera. These facts enable us to come to a trustworthy conclusion as to former climatic conditions—for all we have to do is to examine the conditions under which the existing species presently flourish, and draw the obvious inference. Of

course the larger the number of living species, and the more highly organised these are, the more reliable our theoretical results will be. But suppose our fossils indicate a warm and genial climate, and that the locality in which we discover our section lies far within the Arctic Circle,—what must our conclusion be? Simply this: that the climate of those high latitudes was formerly much warmer than it is now. We appeal to the present, and that is the reply we get. But the next question arises: How could such a climate obtain within the Arctic Circle? This is one of those crucial cases which must eventually determine whether Uniformitarians are justified in maintaining that the present is the exact type of all that has gone before, within known geological periods. According to them it is not necessary to look beyond this earth itself for an explanation of such an apparent anomaly as the occurrence of southern faunas and floras in the Arctic regions. All we have to assume, they tell us, is a former very different distribution of land and water. They refer us to the well-proved fact that there have been frequent considerable elevations and depressions of the land, which must have indirectly affected the climate of wide areas by modifying the course of oceanic and aerial currents. They argue that were the larger land-areas of the globe to be grouped about the equator, with oceanic islands scattered over the higher latitudes, this arrangement of land would induce all the conditions that are necessary to account for the former growth of walnuts and oaks and beeches within the Arctic Circle.

This hypothesis is opposed by others who maintain that no such distribution of land and water existed at the epoch in question. According to them, the position of the main continental ridges and oceanic depressions was established at a very early period in the earth's history. The persistence of these main features, however, does not imply a total invariability of outline. On the contrary, the protuberant areas, it is admitted, have been modified again and again all

through the geological ages—considerable portions having been alternately depressed below and lifted above the sea-level. But as the relative positions of the more important ridges and depressions of the earth's surface—the continental areas and oceanic basins—were determined long anterior to the deposition of the Tertiary strata, and probably date back to azoic times—such a re-arrangement of land and sea as the uniformitarian view requires cannot have taken place. It is further maintained that, even could such a rearrangement be substituted for the present, it would not bring about a genial climate in the Arctic regions. We must look beyond our globe itself, we are told, if we wish to find the key to those greater revolutions of climate of which we have evidence in such a case as the occurrence of a southern flora within the Arctic Circle. The greater climatic revolutions of the past are due, we are assured, to periodical changes in the eccentricity of the earth's orbit, combined with the precession of the equinoxes, and the influence which such mutations must have exerted upon the ordinary agents of geological change.

The soundness of these opposing views must of course be tested by an appeal to facts, and it will be our duty in the course of our investigations to examine all the data which have been adduced in their support. I have referred to them on this occasion merely to show you that above and beyond the more or less obvious interpretation of geological phenomena, larger questions arise, the consideration of which demands not only laborious and far-extended observation, but must call into exercise all the varied powers of the human mind.

In the initial stages of our geological investigations we are occupied in detecting the more apparent resemblances and correspondences between the present and the past. We readily discover in sedimentary strata the evidence of their accumulation by the action of water, nor do we experience

much difficulty in discovering the igneous origin of many rock-masses in regions now far removed from scenes of volcanic activity. But each observation we make and every well-founded correspondence we establish between the present and the past leads on to larger and larger deductions, until, as in the case of our granitic dykes and veins, we eventually find that geological investigations frequently increase our acquaintance with forces now in action and give us some insight into the hidden operations of Nature. It is not indeed too much to say that in many cases our knowledge of such operations is derived in large measure from a study of the effects produced by the work of Nature in past ages. The examination, for example, of the fragmentary relics of ancient volcanoes, in this and other countries where volcanic action has long been extinct, has enabled us to picture to ourselves many details of the structure of those interior and basement parts of a volcanic mountain, which otherwise must ever have remained unknown. *Judd*
The long-continued action of the agents of denudation has often removed those superficial rock-masses which gather around volcanic orifices, so as to lay bare, as in a dissection, the interior and basal portions—showing us the fractured and baked strata through which the heated gases, molten matter, and loose ejectamenta were erupted, and the dykes and veins of crystalline rock which were injected into the cracks and fissures of the shattered strata. Nay, a study of those vast masses and sheets of granitic, gneissose, and schistose rocks, of which large portions of the Scottish Highlands, Scandinavia, and other countries are composed, induces the belief that these rocks originally existed as ordinary sedimentary strata, and that their present crystalline condition has been assumed at a time when they were deeply buried underneath other and of course younger strata. And thus we have hints given us as to what may be taking place now throughout extensive areas underneath the surface of the earth, where other sand-

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stones and shales may be undergoing a gradual metamorphism and conversion into crystalline rocks.

It will be observed that the results obtained by geologists could not have been arrived at had they confined themselves solely to the detection of resemblances and correspondences between the phenomena of the present and the past. The natural forces have always been the same in kind, if not in degree, and we can often watch the gradual development by their means of products which more or less closely resemble the rocks of our sections. But experimental evidence of this kind takes us only a short way, and we are sooner or later confronted by appearances, which are not reproduced by Nature before our eyes. As another example of this I shall adduce one which, although it has far-reaching issues, has yet the merit of being readily comprehended without much preliminary geological knowledge. It is moreover instructive as showing how the imaginative faculty works in a mind trained to clear and steady observation of Nature. The fact that a large proportion of the lakes of the world rest in rocky hollows or basins had been long known before it occurred to anyone to ask how such rocky hollows had come into existence. The question was first asked and the answer given by Professor (now Sir) A. C. Ramsay. He had pondered over the problem for years before its solution dawned upon him. None of the ordinary agents of geological change seemed capable of producing the phenomena. The most common of all denuding agents—water—certainly could not do so, for although it may dig long and deep trenches through rocks, water could not scoop out a basin like that occupied by Loch Lomond, or any of our Highland lakes. The tendency of water is, on the contrary, to silt up and to drain such hollows, by deepening the points of exit at their lower ends. Did the hollows in question occupy areas of depression—had they, in short, been formed by unequal subsidences of the ground? Some considerable inland seas,

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as for example the Dead Sea, and doubtless many larger and smaller sheets of water, owe their origin to local movements of this kind. But it is incredible that all the numerous lakes and lakelets of Northern and Alpine regions could have originated in this way. In many cases these lakes are so abundant that it is hard to say of some countries, such as Finland, and large parts of Sweden, and even of our own islands, whether it is land or water that predominates. If all these numerous and closely aggregated rock-basins represent so many local subsidences, then the hard rocks in which most of them appear must have been at the time of their formation in a condition hardly less yielding than dough or putty. It was suggested that the lakes of the Alps and other hilly regions might have been caused, not by local sinkings confined to the valleys themselves, but by a general depression of the central high-grounds and water-sheds. The subsidence of the central mountains would of course entail depression in the upper reaches of the mountain-valleys, and in this way the inclination of those valleys would be reversed—each being converted into an elongated rock-basin. But a little consideration showed that before the lakes of such a region as the Alps could have been produced in this manner, those mountains must have been some 15,000 feet higher than at present. Or to put it the other way, in order to obliterate the Alpine lakes and restore the slopes of the valleys to what, if this hypothesis were true, must have been their original inclination, the Alps would need to be pushed up until they attained twice their present elevation. Now, we are hardly prepared to admit that the Swiss mountains were 30,000 feet high before the glacial period. If our Alpine and Northern lake-basins cannot be attributed to movements of depression, still less can they be accounted for by any system of fractures;—they lie neither in gaping cracks nor on the down-throw sides of dislocations. In a word, a study of the structure, inclination, and distribution of the rock-masses

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in which our lake-basins appear throws no light upon the origin of those hollows. We probably find in many cases that the position and form of a basin have been influenced in some way by the character of the rocks in which it lies—but we detect no evidence in the rock-masses themselves to account for its production. It is not necessary, however, that I should on this occasion mention each and every cause which has been suggested for the origin of rock-bound hollows. Some of these suggestions are unquestionably well-founded. For example, there can be no doubt that certain lakes have been produced by the sudden damming-up of a valley in consequence of a fall of rock from adjoining slopes or cliffs; others, again, occupy holes caused by the falling in of the roofs of caves and subterranean tunnels; while yet others have been formed by a current of lava flowing across a valley and thus ponding back its stream, just as many a temporary sheet of water has been brought into existence in a similar way by the abnormal advance of a glacier. In these and other ways lakes have doubtless originated again and again, but the causes just referred to are all more or less exceptional, and manifestly incapable of producing the phenomena so conspicuous in the lake-regions of Britain, Scandinavia, Finland, and the Alps.

Ramsay, to whom the varied phenomena of glacier-regions had been long familiar, was struck by the remarkable fact that freshwater lakes predominate in Northern and Alpine countries, while they are comparatively rare in regions further south and outside of mountainous districts. The great development of lakes in Finland finds no counterpart in the low grounds of southern latitudes. It is in regions where glacial action formerly prevailed that rock-basins are most numerous, and this suggested to Ramsay that in some way or other the lakes of the Alps and the North were connected with glaciation. The final solution of the problem flashed upon him while he was studying the glacial features of Switzerland. His scientific imagination enabled him to

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reproduce in his own mind the aspect presented by the Alps during the glacial period, when the great mountain-valleys were choked with glacier-ice which flowed out upon the low grounds of Germany, France, and Northern Italy, so as to cover all the sites of the present lakes. He saw that under such conditions enormous erosion must have been effected by the ice, by means of the rocky rubbish which it dragged on underneath, and that this erosion, other things being equal, would be most intense where the ice was thickest and the ground over which it advanced had the gentlest inclination. Such conditions, he inferred, would be met with somewhere in the lower course of a valley between the steeper descent of its upper reaches and the termination of the glacier. This inference was suggested by the consideration that pressure and erosion would be least when the glacier was flowing upon a steep slope, while at the base of such a slope where the valley flattened out, the ice would tend to heap up, as it were, and produce the maximum amount of pressure and erosion. Thereafter, as the ice continued to flow down its valley, it would become thinner and thinner until it reached its termination—and pressure and erosion would diminish with the gradual attenuation of the glacier. Such conditions, after some time, would necessarily result in the formation of elongated rock-basins, sloping in gradually from either end, and attaining their greatest depth at some point above a line drawn midway between the upper and lower ends of a hollow. There are many other details connected with this most ingenious theory which I cannot touch upon at present. It will be sufficient to say that the observed facts receive from it a simple and satisfactory explanation. Like all other well-based theories, it has been fruitful in accounting for many other phenomena, a study of which has developed it in various directions, and enabled us to understand certain appearances which the theory as at first propounded seemed hardly adequate to

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explain. As a proof of the soundness of Ramsay's conclusion that ice is capable of excavating large rock-basins, I may mention that his theory has led to the prediction of facts which were not previously known to geologists. He had pointed to the occurrence, in many of the sea-lochs of Western Scotland, of deep rock-bound hollows, which he concluded must have been formed by great valley-glaciers in the same way as the hollows occupied by fresh-water lakes in this and other similarly glaciated countries. Some years later, having discovered that the Outer Hebrides had been glaciated across from side to side by a *mer de glace* flowing outwards from the mainland, and having been satisfied as to the truth of the glacial-erosion theory, I was led by it to suppose that deep rock-basins ought to occur upon the floor of the sea along the inner margin of most of our Western Islands. This expectation was suggested by the simple consideration that those islands, presenting, as they for the most part do, a steep and abrupt face to the mainland, must have formed powerful obstructions to the out-flow of the *mer de glace* in the direction of the Atlantic. This being so, great erosion, I inferred, must have ensued in front of those islands. The lower part of the *mer de glace* which overflowed them would be forced down upon the bed of the sea by the ice continually advancing from behind, and compelled to flow as an under-current along the inner margin of the islands, until it circumvented the obstruction, and resumed the same direction as the upper portion of the *mer de glace*. A subsequent careful examination of the Admiralty's Charts of our western seas, which afford a graphic delineation of the configuration of the sea-bottom, proved that the deduction from Ramsay's theory was perfectly correct. Were that sea-bed to be elevated for a few hundred feet, so as to run off the water, and unite the islands to themselves and the mainland, we should find the surface of the new-born land plentifully diversified with lakes—all occupying the

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positions which a study of the glaciation of the mainland and islands would have led us to expect. Among the most considerable would be a chain of deep lakes extending along the inner margin of the Outer Hebrides, while many similar sheets of water would appear in front of those islands of the Inner Group that face the deep fiords of our western shores.

The few examples now given of geological methods of inquiry may suffice to show that the process of reading and interpreting the past in the light of the present necessitates not only accurate observation, but an extensive acquaintance with the mode in which the operations of Nature are carried on. They also serve to show that just as our knowledge of the past increases, so our insight into the present becomes more and more extended. For if it be true that the present is the key to the past, it is not less certain that without that unfolding of the past which a study of the rocks has enabled us to accomplish, we should not only miss the meaning of much that we see going on around us, but we should also remain in nearly complete ignorance of all that is taking place within the crust of our globe. Thus, although our science may be correctly defined as an inquiry into the development of the earth's crust and of the faunas and floras which have successively clothed and peopled its surface—yet that definition is somewhat incomplete. For, as we have seen, this inquiry into the past helps us to understand existing conditions better than we should otherwise do. In this respect it is with geology as with human history. The philosophical historian seeks in the past to discover the germ of the present. He tells us that we cannot hope to understand the complicated structure and relations of a society like ours without a full appreciation of all that has gone before. And so it is in the case of geological history. The present has grown out of the past, and bears myriad marks of its origin, which would either be unobserved or remain totally meaningless to us, were the past a sealed book. No

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student of physical geography, or of zoology and botany, therefore can afford to neglect the study of geology, if his desire be to acquire a philosophical comprehension of the bearings of those sciences. For it is geology which reveals to us the birth and evolution of our lands and seas—which enables us to follow the succession of life upon the globe, and to supply many of the missing links in that chain, which, as we believe, unites the beginning of life in the far distant past with its latest and highest expression in man. By its aid we track out the many wanderings of living genera and species which have resulted in the present distribution of plants and animals. But for geology, indeed, that distribution would be for the most part inexplicable. How, for example, could we account for the often widely separated colonies of arctic-alpine plants which occur upon the mountains of Middle and Southern Europe? How could these plants possibly have been transferred from their head-quarters in the far north to the hills of Britain, and Middle Germany, to the Alps and the Pyrenees? Not the most prolonged and laborious study of the botanist could ever have solved the problem. But we learn from the geologist that the apparent anomalous distribution of the flora in question is quite what his study of the rocks would have led him to expect. He now, indeed, appeals to the occurrence of those curious colonies of arctic-alpine plants as an additional proof in support of his view that during a comparatively recent period our continent experienced a climate of more than arctic severity. He tells us that at that time the reindeer, the glutton, the arctic fox, the musk ox, and other arctic animals migrated south into France, while a Scandinavian flora clothed the low grounds of Middle Europe. By and by, when the arctic rigour of the climate began to give way, the northern species of plants and animals slowly returned to the high latitudes from which they had been driven. Many plants, however, would

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meet with similar conditions by ascending the various mountains that lay in the path of retreat, and there they would continue to flourish long after every trace of an arctic-alpine flora had vanished from the low ground. This explanation fully meets the requirements of the case. It leaves none of the facts unaccounted for, but is in perfect harmony with all. But as if to make assurance doubly sure, Dr. Nathorst, a well-known Swedish geologist, recently made a search in the low grounds of Europe for the remains of the arctic-alpine flora, and succeeded in discovering these in many places. He detected leaves of the arctic willow and several other characteristic northern species in the glacial and post-glacial deposits of Southern Sweden, Denmark, England, Germany, and Switzerland, and thus supplied the one link which might have been considered necessary to complete a chain of evidence already almost perfect.

*Climbing
Mounts*

From this and many similar instances that might be given we learn that the reconstruction of the past out of its own ruins is not mere guesswork and hypothesis. The geologist can not only demonstrate that certain events have taken place, but he can assure us of the order in which they succeeded one after the other, during ages incalculably more remote than any with which historians have to deal. The written records out of which are constructed the early history of a people cannot always be depended upon,—allowance must be made for the influences that may have swayed the chroniclers, and these are either unknown or can only be guessed at. It follows therefore that events are seldom presented to us in a consecutive history exactly as they occurred. They are always more or less coloured, and that colouring often depends fully as much upon the idiosyncrasies of the modern compiler as upon those of the contemporaneous recorder. The geologist has at least this advantage over the investigator of human history, that his records, however fragmentary they may be, tell nothing

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 more and nothing less than the truth. Any errors that arise must be due either to insufficient observation or bad reasoning, or to both, while the progress of research and the penetrating criticism which every novel view undergoes must sooner or later discover where the truth lies. In this way the history of our globe is being gradually reconstructed—to an extent, indeed, that the earlier cultivators of the science could not have believed possible. But although many blanks in the record have been filled up, and our knowledge will doubtless be yet greatly increased, it must nevertheless be admitted that this knowledge will always bear but a very small proportion to our ignorance. In this, however, there is nothing to discourage us, as we may be quite sure that the work remaining to be done will far exceed all the energies of many generations to accomplish.

It is sometimes objected to Geology that its results are not always so exact as those which are obtained by an experimental science like Chemistry. We are reproached with the fact that our theoretical conceptions undergo frequent modification, and are even often abandoned, to be succeeded by others which, after flourishing for a time, are in like manner overturned and thrown aside. But the same reproach, if it be one, might be brought against other sciences. Each advancing science has its problems and speculations. And we cannot often feel assured that the solution now given of those problems will in all cases stand the test of time. Our theoretical conceptions of the ultimate constitution of matter, for example, have within comparatively few years undergone considerable change, and yet no one values Chemistry the less. Let our theories be what they may, they do not and cannot overturn the results obtained by verified observation and often-repeated and varied experiment. It remains for ever true that water is composed of oxygen and hydrogen, let our views of the atomic theory change as they may. And so it is not less certain that strata of conglomerate and sand-

stone containing marine or fresh-water fossils are of aqueous origin, however much our theoretical conceptions may vary as to the uniformity in degree between the past and present operations of Nature. It is true we did not see the conglomerate and sandstone in process of formation, but we know by observation that these rocks exactly resemble deposits of gravel and sand which are now being accumulated in water. Nature in this case makes the experiment for us, whereas the chemist has to do this for himself. The latter, having well ascertained by varied experiments the composition of certain samples of water, henceforth concludes that all water is made up of the same two gases in definite proportions. But this conclusion of his is just as much an assumption as the inference of the geologist that strata containing marine or fresh-water fossils are aqueous accumulations. It is when we come to the larger generalisations of our science that we are more likely to go astray. The problems we have to solve demand not only an accurate knowledge of widely scattered phenomena, but a ready command of logical analysis. The facts may be sufficiently abundant, but if we reason badly we of course miss their meaning. Or, on the other hand, the evidence may be more or less imperfect. There are blanks which we fill up with conjecture—which can do no harm so long as we do not treat our conjectures as if they were facts. But when the gaps in the evidence are numerous each theoriser will fill them up after his own fashion, and very various results will thus be obtained. Even in cases of this kind, however, a rigorous application of logical analysis will enable us to detect the fallacies which may underlie all the competing theories; and we are thus prepared to frame a new explanation for ourselves, and to set about searching for additional facts to prove or disprove our notions. In all such investigations it is obviously the duty of a careful observer and theoriser to see well to his premises—to be absolutely sure as to his facts, and to distinguish clearly be-

tween what is substantial knowledge and what is mere conjecture. He will thus be in a position to judge whether his conclusions are based on a solid foundation or not. In a science of observation like Geology, theory is necessarily often in advance of the facts. Some, indeed, have insisted that all conjectural explanations are quite a mistake—that it would be better to avoid theorising altogether, and to wait patiently until the chain of evidence had completed itself. I am afraid that, were it possible to follow this advice, we might often have to wait a very long time. After all, a heap of bricks is only a potential house,—it will not grow up into walls without the aid of architect and builder. Discoveries in science have no doubt been made occasionally by isolated and haphazard observations ; but that is exceptional, and we should not be where we are now had the examination of Nature been always conducted after such a fashion. If additional evidence be required we must first have some notion where to look for it. In other words, it is essential to progress that we should have preconceived opinions or theories, which enable us to arrange the facts we already possess and to point out the directions in which further evidence may be looked for. We cannot be too careful, however, that our preconceived notions do not lead us to colour the evidence or to blind us to facts that tell against our views.

Good (Every theory should be considered only provisional until its truth has been fully demonstrated by an overwhelming array of testimony in its favour. Until this consummation is arrived at we must be constantly testing its truth, and be ready to abandon it at once whenever the evidence shows it to be erroneous. The failure of one theory after another need not disconcert or discourage us—for each failure, by reducing the number of possible explanations, must necessarily bring us nearer to our goal—the truth. I cannot but deem it a strong point in favour of Geology as a branch of education that it not only cultivates the faculty of clear and

continuous observation, but abounds in unsolved problems which are ever suggesting new ideas and thus stimulating that imagination which is one of the noblest gifts of our race. It is no reproach that the progress of our science is marked by the modification and abandonment of numerous hypotheses and theories. On the contrary these afford a measure of the rate at which geology advances—just as this last yields the strongest testimony to the good results that accrue from having some provisional view by which to direct the course of our observations.

It is unavoidable that in the onward march of a science the facts become at last so numerous as to task all the energies of its votaries to keep abreast of their time. When a beginner first surveys the wide field embraced by geological inquiry, he may not unnaturally experience a feeling akin to despair. How is it possible, he may think, that I can master all these manifold details—how can I test the truth of all those numerous inferences and conclusions—and yet have sufficient leisure and energy left to undertake original observation? Well, no one can hope to advance the science in all its departments. When we reflect that in order to obtain a complete comprehension and mastery of the existing condition of things we should require to be adepts in physics, mechanics, chemistry, and every branch of natural science, it is obvious that such a perfect knowledge is beyond attainment. It is needless, therefore, that we should strive to become ‘admirable Crichtons’ in this nineteenth century, and no beginner need be discouraged by the greatness of the science which he desires to cultivate. It is only by division of labour that so much has been accomplished; and the results are now so systematised that it is quite possible for any intelligent inquirer to gain a thorough comprehension of the principles of the science. But this it is absolutely necessary to acquire, and the student, therefore, should at first devote all his energies to learn as much as he

can of those principles and their application. When he has progressed so far, he is then ready to set out as an explorer in the well-assured hope that if he be true to the logical methods which have hitherto succeeded so well, he will not fail to reap his reward in the discovery of new truths. But to secure success we must be content to be specialists. In other words, we must concentrate our energies upon some particular lines of inquiry, and do our utmost to work these out in all their details. At the same time we should make a great mistake if we did not always keep in mind the broader bearings of our science, and endeavour to maintain as wide a knowledge as we can of all its branches. Each of these, we may be sure, has something to tell which will aid us in our own special inquiries. We cannot, therefore, afford to neglect the side-lights which are thrown upon our path from the lamps of others who are working in adjacent fields. One cannot help thinking that many specialists would have given us more and better work if they had not allowed themselves to be cramped and narrowed by continuing too long in one rut or groove. They dig so deep that they get into a hole out of which it is sometimes difficult to climb, and thus not infrequently the work being done by fellow-labourers escapes them, and they miss the suggestions which a knowledge of that work might otherwise have yielded them.

I have said nothing as to the practical applications of our science—that branch of our subject which is termed Economic Geology—not because I consider it the less important, but because its value is generally recognised and need not now be insisted upon. Many, I do not doubt, enter upon their geological studies with a distinct view of obtaining from the science such help as it can afford them in the practical pursuits of life. To such inquirers it will be my pleasure not less than my duty to give every assistance that is in my power. But I would point out to them that there is no short cut to the attainment of the knowledge they are

in quest of. The study of economic geology cannot be separated from that of the recognised principles and methods of inquiry which must be followed by the scientific investigator. On the contrary, the more thoroughly we devote ourselves to the prosecution of Geology for its own sake the better able shall we be to appreciate its economic bearings.

In beginning the duties of this Chair, if I enjoy certain advantages over my predecessor, I also at the same time labour under considerable disadvantages. The Class Museum formed by him, and the other appliances and aids to teaching which he laboriously gathered together have been generously handed over to the Chair—and this, I need not say, has greatly smoothed my path. But, on the other hand, he has left behind him a reputation which must bear hard upon me. He has not only sustained but increased the fame of what has been termed the Scottish School of Geology, and I feel that it will task all my energies to emulate the high standard he maintained as a teacher. It is not without diffidence, therefore, that I commence this course; but my hope is that the love of science, which has hitherto carried me over many years of a laborious occupation, may at least succeed in warming and sustaining the enthusiasm of those who come here to study with me what Geology has to reveal concerning the present and the past.

On the whole a very good
beginning JH
Mar 10 1862





